Space Human Factors Advanced Development Projects

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Abstract

The NASA Space Human Factors community engages in activities that range from basic research through advanced development projects to applications associated with ongoing programs such as the International Space Station and the Shuttle. This panel of NASA human factors specialists will present information relating to advanced development projects aimed at the creation of tools that can be applied to the analysis, design and evaluation of space vehicles and operations, and future space vehicle design concepts. The projects are: "The voice of the customer" - a description of the multiple pathways used to obtain astronaut information and opinion; International Space Station emergency medical procedure evaluation and redesign; the "magic windows" project which provides a multifunctional display system for operations and personal use on space vehicles and analogs; analytical approaches to digitally scanned crew member anthropometric data; crew member activity measurement, modeling and scheduling; evaluation of the upgraded displays of the Space Shuttle cockpit; and finally a description of the updated, electronic version of the space human factors engineering database.

The Voice of the Customer

The International Space Station (ISS) poses many challenges for human factors and habitability. For example, the ISS hosts long duration space missions of three to six months, as opposed to short duration Shuttle flights. In addition, the vehicle must be designed to support work and personal activities. Still another issue is that the ISS is truly international and must support a multi-cultural crew. The ISS comprises multiple modules (rooms) and nodes (hallways), built in different countries according to different schedules. The modules and nodes are assembled in orbit, and actual operation during a real mission is the first and only integrated performance test, especially for human performance and habitability. The astronauts' first mission is most certainly the first exposure that they, the primary customer for space human factors, have to the integrated environment and the demands of actual living and working on ISS.

The task loading includes a variety of operations from construction, maintenance, housekeeping, exercise, public affairs, scientific experiments, to recreation, hygiene and sleep. The actual use of the ISS for a real mission is also the first opportunity for human factors specialists to receive feedback from the customer. This customer feedback is an essential part of the human factors design-test-redesign loop. For example, it is critical for human factors designers and mission planners to acquire user feedback on:

- Equipment/workstations (e.g. laboratory design, maintenance of equipment or systems, design, quantity, and location of sleep quarters)
- Environmental conditions (e.g. illumination, accessible volume, noise and vibration)
- Operational context (e.g., implementation of a stowage plan that maintains acceptable levels of safety, efficiency, productivity, comfort; interaction between layout and traffic patterns)

Crew debriefs - extended interviews of the crewmembers on prescribed topics - are the primary source of customer feedback. A dedicated Habitability and Human Factors debrief has been conducted for each of the ISS crews to date as well as the previous U.S. astronauts who stayed for 6 months on board the Russian Mir Space Station. In these debriefs, crewmembers answer specific questions designed to elicit descriptive feedback on general habitability characteristics of the ISS, and on specific difficulties. Standard templates of topics and open-ended questions are used for each debrief to facilitate longitudinal analysis. In addition, debrief content is tailored to specific missions by including more focused questions relevant to the mission at hand.

One drawback of the crew debriefs is that the feedback is delayed and therefore potentially inaccurate due to such mechanisms as the halo effect. (In a rare instance, one of the crews requested an in-flight debrief.) As the ISS missions can last up to six months, accurate recall of lowlevel details is difficult. To address this issue, a second means of collecting customer feedback is via an electronic in-flight user-initiated anomaly reporting system. On the form, the crewmember describes the details of the issue, categorizes it, and submits the feedback immediately to the ground team. The anomaly reports are a reactive means of gathering feedback however, in certain circumstances, there is a need to actively focus the user's attention and gather feedback. For example, one sleep station was developed on an accelerated schedule and therefore received abbreviated evaluation. The functionality of a sleep station for supporting human performance is particularly impacted by the lack of gravity. Therefore, there is a need to assess this important piece of habitability hardware in long-term zero gravity use in order to identify potential design improvements. In these instances, a specific *in-situ* usability engineering assessment is conducted wherein the crew is requested to perform various actions with the targeted hardware and answer specific questions.

As important as it is to collect feedback from the user on habitability, it is of equal importance that something be done with that feedback. To that end, this program has established a means of identifying and logging habitability issues from ISS missions and the associated corrective actions. The actions include creating or modifying requirements and hardware or operations changes. It is hoped that the increased emphasis on habitability for ISS and the lessons identified will generalize to other long duration human-tended extraterrestrial ventures such as planetary habitats and flight to Mars.

ISS Emergency Medical Procedures

Work is being carried out to upgrade the emergency medical procedures on board the ISS. Emergency medical capabilities currently available were developed over recent years to provide the training and equipment to resuscitate an injured crewmember, along with a reference book (called the Medical Checklist) for the crew's use. An ISS crewmember is designated as Crew Medical Officer (CMO) and is trained in these procedures. No physicians are currently planned to be crewmembers in the initial phase of the ISS program. As a result, crews will have no specialist medical knowledge available on orbit, but will need to rely upon air to ground communication and the Medical Checklist, a limited medical pack and their recall of the emergency medical procedure training.

The human factors investigations are addressing crew training, likely medical emergency scenarios, air to ground communications, and predicted patient outcome. The aim is to determine user interface shortfalls (both in on-orbit and ground support), and to recommend solutions that will improve survival chance of crewmembers in the event of a medical emergency. The initial work includes gathering information on the current practices in analog facilities and environments such as Navy medical corpsman training. In addition, analyses of navigation and layout of the Medical Checklist and algorithms are underway. A pilot test, using an advanced patient simulator, is underway in collaboration with a Harvard Medical School student cohort. These preliminary tests assess the readiness and usability of the proposed ISS critical care revised algorithms via paper and computer display interfaces. The next stage will be the evaluation of the Checklist's navigation and layout of medical procedures with a cohort of CMO's.

Magic Windows for the ISS

The success of an ISS mission is dependent on crew performance and maintenance of productivity, against a background of confinement in a largely unchangeable environment. Psychological well being on long duration missions has been identified as an issue that affects crew performance, productivity, and ultimately mission success. (Palinkas, 1990, Nicholas et. al., 1990.) A potential solution to this concern is an Imagery System - a common information display system anywhere on the ISS. This Imagery System could serve as a "magic" window that will display desired information or images (recreational or operational) such as family pictures, movies, assembly procedures, or a moving scene that changes as you advance on an exercise machine. Because this kind of integrated Imagery System is a relatively new concept for use in human space flight, functional and technical requirements need to be defined before implementation.

The goal of this project is to report on the requirements for the system, to implement prototype systems, to perform usability testing of the systems, and to develop a training manual. Preliminary efforts have included developing a survey in order to determine the desired functional requirements. The survey recipients included habitat chamber study participants, flight crew trainers, flight surgeons, and other flight medical personnel. A search for state-of-the-art screens has been conducted and an initial list of requirements has been created. Also information on analog environments was compiled for use as a test bed for the initial survey including: Antarctica, Devon Island in the Canadian Arctic and the Aquarius Habitat, located off of Key Largo, FL. Finally, information has been collected on lessons learned from ISS, Mir, and Skylab mission debriefs.

Analysis of Scanned Anthropometric Data

There are numerous databases that provide volumes of information collected using traditional anthropometric methods (Anthropometric Survey of U.S. Army Personnel, 1988; NASA Reference Publication No. 1024, 1978; Japanese anthropometric data handbook, 1988). The Anthropometric and Biomechanics Facility (ABF) at the Johnson Space Center has also been responsible for gathering and analyzing the physical dimensions of astronauts and astronaut applicants. The ABF maintains a database of anthropometric data from over 900 astronaut applicants (including astronauts who were selected since 1985). Each file contains about 28 body segment specific anthropometric data points, which have been used to conduct various workplace, hardware evaluations.

Unfortunately, these uni-dimension based anthropometric databases are not adequate to generate digital human models that can be applied in a wide range of design applications. (Vasu et.al., 2000). This is primarily due to the fact that uni-dimensional anthropmetric databases do not include surface contours of body segments and volumetric data. Hence, graphical representations of human figure models have not been accurate. With the advent of laser scanning technologies, it has become possible to gather two- and three-dimensional anthropometric data. Three-dimensional anthropometric data are capable of providing a better representation of physical attributes in computer-graphics-based human models and may enhance the analytical capabilities for conducting human-work interface evaluations.

The primary objective of this project is to enhance the capabilities of the ABF, specifically in the areas of handling and developing analytical tools for three-dimensional anthropometric data. The ABF has obtained 3-D scanned data of 126 astronauts from the CEASAR (Civilian American and European Surface Anthropometry Resource) project coordinated by human factors colleagues at Wright Patterson Air Force Base (WPAFB). Three goals are identified:

- Develop analytical software tools to process whole-body scanned data.
- Verify, modify, and validate the analytical software results
- Develop statistical analysis software to perform gap analysis on existing space hardware.

The second objective of this project is to develop a methodology to perform whole-body percentile analyses. Percentile data are useful to determine the limiting values of particular body segments or dimensions (such as arm reach, height, girth). Normally, these data are available in several of the above-mentioned handbooks. However, to represent a 5^{th} percentile or a 95^{th} percentile American male in a computer-generated graphics environment, users were limited to predicting other dimensions through correlation-based models. While these models are helpful to accomplish the task of developing human models, our experience has shown that the results from manipulating human figures based on this estimated data are often inaccurate. Hence, we are working with personnel at the U.S. Army R&D Center (NATICK) and the WPAFB to create an analytical tool that will generate a model based on an actual person's whole body scan whose specific uni-dimensional or a composite dimension (e.g. leg reach at a specific knee and hip angle) is representative of a user-defined percentile.

Crew Member Activity Scheduling

Short duration shuttle flights are very highly orchestrated with crewmember activities being planned in great detail well ahead of a mission. Longer duration missions on the International Space Station provide much greater opportunity for temporal variability to creep into the planning and implementation processes. This variability has positive learning components and negative fatigue influences. Furthermore, the local knowledge and inclinations of long duration crewmembers is such that there is a trend for much greater levels of autonomy. (Peacock, Prouty and Blume Novak, 2002)

The human factors community is collaborating with colleagues in the Program Office and Mission Operations to improve the data collection of "actuals" for comparison with planned timelines. This evidence is being used for the development of models that can be used for planning and real time evaluation of alternative scheduling strategies. The activity is also linked to much longer term questions related to planned and unplanned maintenance and the resource demands for the limited (3 person) crews to perform "payload" work.

The first challenge in crew activity scheduling is to define the time available during each flight day for sustaining activity (sleeping, eating, exercising, hygiene, other personal time) and "work" activity (logistics, research, maintenance, training, planning, housekeeping etc.) The general blocks of time for these activities are preplanned. The next step is to find ways of obtaining better estimates of the time taken to carry out individual activities and generic activity elements - such as setup, procedure review, actual experimentation, tear down and reporting. Earth based estimates are not always accurate and crew members and ground support personnel are understandably not always enthusiastic about the chore of detailed time data collection. There are also contingencies, such as responses to caution and warning alarms, activities associated with visiting space vehicles and communications with ground personnel that cannot be accurately measured or estimated. Crewmembers also have weekends. Given the available data, the next task is to create the time based model of activities that is the basis of activity scheduling.

The current approach is through the On-Orbit Operations Summary (OOS), the On Board Short Term Plan (OSTP) and the Task List. These time management devices have increasing levels of precision. The OOS is very general, the OSTP is much more detailed and the "Task List" is a device that allows crew members to select which activities they do on a particular day, given the constraint that certain preplanned tasks must take precedence. This move towards greater crew autonomy is generally accepted as positive. An enhancement to the task list that is being considered involves a greater facility for evaluation of resource requirements before a commitment to a schedule. Finally, given better time data, plans are in hand to develop simulations of ISS operations that involve time variant activities such as interruptions and contingencies with due reference to resource limitations and individual differences.

Upgraded Displays for the Space Shuttle Cockpit

During a mission of the Space Shuttle, the crew can view dozens of different display formats on the computer screens in the cockpit. The computer screens in each Space Shuttle orbiter are being upgraded from monochrome cathode ray tubes (CRTs) to color liquid crystal displays, which are part of the Multifunction Electronic Display System. Advantages of the new displays (called Multifunction Display Units, or MDUs) include lighter weight and lower power requirements than the CRTs. An added benefit is that the MDUs support greater use of color and graphics than the original CRTs. NASA is now developing new display formats that take advantage of these benefits (McCandless and McCann, 2001). As a means of determining the effectiveness of the new display formats, NASA is conducting three types of evaluations: a hardware evaluation, a standards evaluation, and a user evaluation.

In the hardware evaluation, color and luminance characteristics of the MDUs were measured with light meters at NASA Johnson Space Center. The colors shown on the MDUs are specified by setting each channel (red, green, and blue) to a level ranging from 0-15. For example, the setting 15,15,0 produces yellow. One of the notable results of the evaluation is that the actual color output on the MDUs is approximately constant for large channel settings. Channel settings between 9-15 produce similar chromaticity and luminance values in standard units defined by the Commission Internationale de l'Eclairage (CIE) (Wyszecki and Stiles, 1967). For example, the CIE xyY coordinates were identical for channel settings of 0,9,0 compared with 0,15,0.

In the standards evaluation each display format was reviewed on the basis of whether it complied with the guidelines specified in the Man-Systems Integration Standards document (1995) as well as internally produced documents on user interface specifications. In cases where the display formats did not comply, changes were made to the display format or else explicit rationales were written justifying why the display format was in non-compliance. For example, one of the guidelines states that a single word shall have no more than one abbreviation. In the case of the display formats, exceptions were made for a number of words, such as "pressure", which was abbreviated as "Press" or "P" depending on the space constraints. The context of the display format aids the crew in understanding the abbreviation.

The user evaluation is scheduled to be run in 2004, using astronauts to view the display formats in the cockpit of the Shuttle Mission Simulator (SMS). Measurements will be taken of situation awareness, workload and performance. Situation awareness will be quantified with the Situation Awareness Global Assessment Technique (SAGAT) (Endsley, 1995). The metrics being considered for workload are the Bedford scale (Roscoe, 1984) and the NASA Task Load Index (TLX) (Hart and Staveland, 1988). Performance will be measured by measuring the crew's response time and accuracy in performing procedures associated with nominal and off-nominal events.

Space Human Factors Engineering Database

The NASA Space Human Factors Engineering (SHFE) Project addresses critical questions that must be answered to enable long duration human space flight missions, including longer stays on the International Space Station and eventual exploration-class missions. The SHFE Project focus areas, documented in the Space Human Factors Engineering Project Plan (Johnson Space Center, 2001) and the Space Human Factors Engineering Implementation Plan FY2002-FY2003 (Johnson Space Center, 2002) have been established and prioritized through reviews by a variety of internal and external experts in human factors and in human space flight. The Space Human Factors Engineering Database task was initiated to link questions and answers. The database consists of six classes of information:

- critical questions identified by NASA.
- information needed to answer the critical questions
- citations of published research
- contact information for individuals with relevant publication
- draft requirements undergoing review by users and by subject matter experts.
- approved requirements.

The database is designed to serve a variety of users. Researchers will be able to search it for recently published results. SHFE Project management will use its information on critical questions and recently completed research or work in progress to identify holes and gaps to which special attention must be paid. Engineers and operations personnel will examine requirements still in the draft stages and have the opportunity to comment on their values and costs to designers and mission planners. Program managers will have a source of carefully reviewed human factors requirements from which to draw requirements for specific programs. In addition, the database will provide a springboard for redesigning and updating the NASA-STD-3000, Man-Systems Integration Standards (NASA, 1995), which has been the basis for human factors requirements for several programs and projects including International Space Station. (http://msis.jsc.nasa.gov)

Conclusions

These Advanced Development Projects represent some of the ongoing activities of the NASA Space Human Factors Project. They are based on a "pull" through the experience of the leaders in their day-to-day involvement with NASA operations such as the International Space Station and Shuttle, and a "push" from the human factors research community through involvement in broad based conferences such as the HFES Annual Meeting.

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